National Aeronautics and Space Administration

R&D Achievements:

Collaboration & Innovation: Innovators Driving Discovery

A Report on the FY 2009 Internal Research and Development Program | Goddard Space Flight Center

FY | 09

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National Aeronautics and Space Administration

About the Cover

Among many other things in FY 2009, Goddard technologists won new work, secured follow-on funding to mature new technologies, formulated concepts, and validated new instrument concepts in flight demonstrations — success that benefitted Goddard and the scientific community as a whole. These are just a few of the technologists who helped make the year so successful. Top: Bo Naasz; Bottom (left to right): Matt McGill and Scott Janz; Kongpop U-Yen; Jennifer Eigenbrode; and Michael Collier.

One

Message from the Chief Technologist: A Promising Trend

The Merriam-Webster dictionary defines a "trend" as something that extends in a general direction or follows a general course. Over the past several years, Goddard's Internal Research and Development (IRAD) program has been trending in an upward trajectory. In FY 2009, IRAD-sponsored teams won more than $135 million in new missions or follow-on funding — an 85 percent increase over the $73 million earned in FY 2008. This is success by any measure.

Although it is heartening to see the upward trend in new funding, financial success is not our only measure of accomplishment. Just as important is the steadfast progress our innovators are making to secure the Center's future. During the fiscal year, many of our technologists validated new capabilities during aircraft flights. They secured provisional patents. They forged collaborations with industry and academic teams. They created new capabilities that will benefit technologists across the Center, and they formulated concepts for future science and exploration missions. Their successes benefited Goddard and the entire scientific community as a whole.

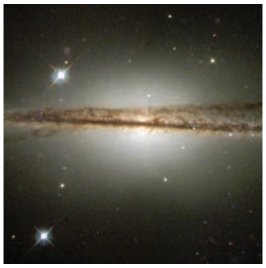
Reasons for Success

I believe several factors have contributed to our success.

In an era of declining R&D budgets, it makes good business sense for organizations to focus on specific areas offering the greatest opportunities. This assures the most efficient use of capital and human resources, ultimately assuring long-term viability and meaningful work for Goddard's highly skilled workforce. Four years ago, we revamped our R&D investment program and aligned it more closely with six specific areas in which Goddard traditionally excelled. By focusing on these areas or lines of business, we could more systematically decide which business opportunities offered the greatest impact and/or the greatest probability of follow-on funding.

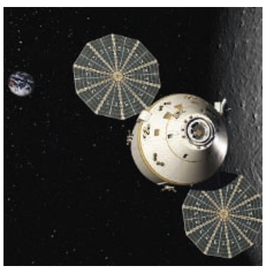
Our adherence to sound business practices has paid dividends. As the numbers show, we are using our precious resources wisely. We are winning new work and securing follow-on funding to mature new technologies. Through new programs aimed at fostering innovation (see Chapter 7 for details), we are giving our technologists the tools they need to drive potentially revolutionary technology. As this year proved, through collaboration and innovation, our innovators are driving discovery.

Peter M. Hughes
Chief Technologist

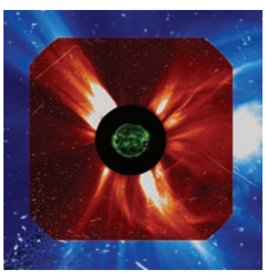


Astrophysics

Earth Science



Exploration



Heliophysics

Planetary & Lunar Science

Two

A Focus on Lines of Business

Over its 50-year history, Goddard has evolved into a center of excellence in heliophysics, astrophysics, planetary and lunar science, Earth science, communications and navigation, and exploration. These six areas now serve as the Center's official "lines of business" — areas on which Goddard decisionmakers base technology investments and new business pursuits.

Whether the R&D investment is made to win a near-term prospect, prepare us to win a longer-term opportunity, or drive the development of a totally new mission or instrument concept, all awarded IRAD tasks map to one or more of these lines of business. This approach has improved our bottom-line, while giving Goddard innovators a frame of reference to plan and carry out their work.

In FY 2009, we funded 12 "capture" tasks and selected 115 R&D proposals that specifically addressed the six lines of business or those that cut across multiple line-of-business areas. Crosscutting technologies include electronics, orbit determination, propulsion, and critical next-generation instrument components.

Goddard's Strategic Lines of Business

Astrophysics focuses on missions and technologies aimed at answering: How do galaxies, stars, and planetary systems form and evolve? Which planets might harbor life? What happens to space, time, and matter at the edge of a black hole?

Communications and Navigation includes technologies needed for responsive communications and navigation supporting the Exploration, Space Operations, and Science Mission Directorates.

Earth Science focuses on developing technologies needed to observe and understand changes in Earth's climate system. Technologies include state-of-the-art sensors and observational platforms.

Exploration addresses technologies and systems needed to explore the Moon and Mars, including, for example, advanced sensors and platforms and autonomous rendezvous and docking techniques.

Heliophysics addresses solar structure and magnetic activity, solar wind, solar disturbances, and their effects on Earth's upper atmosphere. Wavelength coverage spans gamma rays to microwaves and includes particles and fields.

Planetary and Lunar Science supports new scientific measurements to explore the solar system. Primary research areas include instruments for landers and orbiting spacecraft.

Three

IRAD Enables Discovery for the Nation's Scientists

The primary purpose of the IRAD program is assuring the Center's competitive edge and winning new work in areas deemed strategically important to Goddard. Our investment program uses many metrics to gauge success — winning new missions and follow-on R&D funding, securing flight opportunities, and studying important new missions.

> "Everything we do at Goddard is not for our scientists. Rather, we are bringing together the unique capabilities of a NASA center to enable the science community as a whole."
>
> – Nicholas White, Director, Astrophysics Science Division

Although our R&D program is geared to maintaining our competitive posture, we also make these investments to help the scientific community as a whole. Our investments in instrument technology are resulting in the start of new missions, which will allow scientists worldwide to carry out research and make discoveries. Examples include the International X-ray Observatory, the Gravity and Extreme Magnetism SMEX (GEMS) mission, and Astro-H, all of which will provide a guest observer program.

In this chapter, we highlight the year's most noteworthy accomplishments and how they benefit the community at large.

The crowning achievement of any space-related R&D program is an investment that leads to the award of a new spaceflight mission. In FY 2009, NASA awarded Goddard a new Small Explorer mission made possible by the Center's support of a revolutionary new astrophysics instrument.

Opening the Frontier of X-ray Polarimetry

In the summer, NASA selected Goddard's Gravity and Extreme Magnetism SMEX (GEMS) team to build one of the Agency's two Small Explorer missions, capping a multi-year effort that included significant IRAD investments in the development of the world's first time-projection chamber polarimeter needed to measure the polarization of X-ray emissions.

Scientist Phil Deines-Jones used IRAD funds to develop the world's first time-projection chamber polarimeter, which will fly on the Gravity and Extreme Magnetism SMEX (GEMS), a new Explorer mission.

The $105 million mission, led by Principal Investigator Jean Swank, will open a new window on the universe and provide a guest observer program in which the scientific community can participate. GEMS will deliver never-before-obtained measurements of how fast black holes spin and how their spin rates affect the curvature of space-time. Answers to those questions will revolutionize scientists' understanding of strong field gravity and magnetism and change the way they view the universe.

> "Winning this mission shows the value of focused R&D investments addressing the most critical technologies. Our investment made a difference and resulted in the team winning this important new mission."
>
> – Peter Hughes, Chief Technologist

GEMS will answer these questions through pioneering X-ray polarimetry measurements. Until now, obtaining these measurements was not possible because of poor instrument sensitivity and difficulty capturing enough X-ray photons. The IRAD program began funding the enabling polarimeter technology six years ago. (Investment Area: Astrophysics)

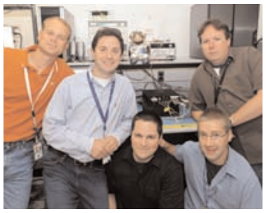
Principal Investigator Bo Naasz successfully demonstrated the Relative Navigation System (RNS) during the Hubble Servicing Mission. He is pictured here with RNS, which was installed inside the Shuttle cargo bay.

In FY 2009, Goddard technologists and scientists either demonstrated their technologies on actual spaceflight missions or prepared instruments for flights in FY 2010 and beyond. The demonstration missions will advance the technology readiness levels of these instruments, leading the way for potential missions in the future.

Proving Validity of Relative Navigation System

A team of IRAD-funded technologists demonstrated that spacecraft could operate in close proximity with little or no human intervention — an important capability for future science and exploration efforts. While astronauts rendezvoused with, grappled, and then redeployed the Hubble Space Telescope during the 2009 servicing mission, the team simulated the same exacting maneuvers using the Relative Navigation System (RNS), which included three cameras, the Navigator GPS receiver (see page 5), and the SpaceCube computer system (see related stories, pages 8 and 21). Now that the team has proved the viability of autonomous navigation, the technology now is being considered for a Hubble de-orbit mission at the end of the observatory's operational lifetime and possible sample-return missions. (Investment Area: Communications and Navigation)

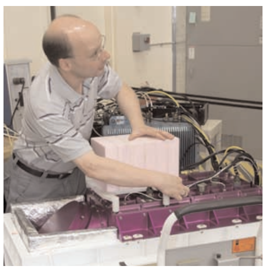
Navigating in Low-Signal Environments



The Goddard Navigator team demonstrated its technology — acquiring GPS in low-signal environments — during the Hubble Servicing Mission in 2009.

GPS receivers are only as effective as the signals they receive. Thanks to a team of IRAD-funded technologists, even those GPS receivers operating in weak-signal areas are able to acquire the precise GPS radiowave signal to determine their location. The Navigator GPS receiver was demonstrated for the first time during the Hubble Servicing Mission as part of the Relative Navigation System demonstration (see page 4). Navigator proved highly effective at quickly finding, acquiring, and tracking weak GPS signals. Honeywell is commercializing the technology, specifically to build a receiver for the Orion spacecraft. The team provided a Navigator test unit to the Geostationary Operational Environmental Satellite-R program and is now building receivers for the in-house Global Precipitation Measurement mission. (Investment Area: Communications and Navigation)

Earth Science Takes Flight on Global Hawk



Scientist Matt McGill tests the Cloud Physics Lidar before flying the instrument on the maiden flight of NASA's Global Hawk aircraft.

Scientist Matt McGill used IRAD funds to modify the Cloud Physics Lidar to fly on an unmanned platform. In FY 2009, he demonstrated the instrument on the maiden scientific flight of NASA's first unmanned aircraft system — the Global Hawk. The Global Hawk mission, managed by Goddard scientist Paul Newman, also carried the Ultraviolet-Visible Spectrometer developed by scientist Scott Janz to validate Aura measurements. Janz is using lessons learned to build a next-generation instrument that might be suitable for a future Earth science mission. (Investment Area: Earth Science)

Fast Track To Space Via New Micro-Satellite

John Keller helped Principal Investigator Michael Collier develop MINI-ME, one of the IRAD-developed instruments that will fly on a mini-satellite in 2010.

Three Goddard scientists — Michael Collier, Doug Rowland, and John Sigwarth — delivered IRAD-funded instruments to the Marshall Space Flight Center in FY 2009 for integration onto NASA's new micro-satellite, the Fast, Affordable, Science and Technology Satellite, which will make its maiden flight in mid-2010 aboard a Minotaur IV launch vehicle. The instruments — the Miniature Imager for Neutral Ionospheric Atoms and Magnetospheric Electrons (MINI-ME), Plasma Impedance Spectrum Analyzer (PISA), and the Thermospheric Temperature Imager (TTI) — will study different processes in Earth's upper atmosphere and the effects of solar activity in this region. The ultimate goal is to fly these miniaturized, low-power instruments on a future NASA mission. (Investment Area: Heliophysics)

> "This is a real feel-good success story. We could not have done this without the generosity of a lot of people. This is the way the IRAD program is supposed to work."
>
> – Scientist Michael Collier, MINI-ME Principal Investigator

High Energy Telescope Demonstrated on Balloon Flight

Technologist Scott Barthelmy developed and designed a cadmium-zinc-telluride-based detector array for the High Energy Telescope (HET), one of three instruments that could fly on the proposed X-ray Imaging Survey Telescope. In 2009, he tested a mini version of the IRAD-funded HET instrument on a balloon flight. The entire detector system, which included 64 detectors, 4,096 pixels, electronics, and mask, performed flawlessly. Barthelmy plans two more balloon experiments in 2010 and 2011. (Investment Area: Astrophysics)

Follow-On Funding to Advance Technology Readiness Levels

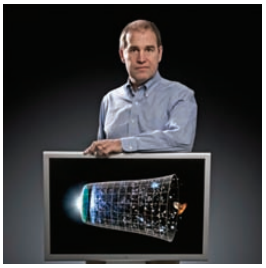
The IRAD program provides seed funding to advance promising new technologies; it is not meant to provide cradle-to-grave support. Therefore, a key IRAD success metric is whether principal investigators succeed in securing follow-on funding to further advance their technologies. FY 2009 was a particularly good year for IRAD-funded principal investigators who secured hundreds of thousands of dollars in new funding.

Follow-on awards came from the Earth Science Technology Office (ESTO), Exploration Technology Development Program (ETDP), Astronomy and Physic Research and Analysis (APRA) program, Research Opportunities in Space and Earth Sciences (ROSES), Advanced Information Systems Technology (AIST), Planetary Instrument Definition and Development Program (PIDDP), and Instrument Incubator Program (IIP), just to name a few. Below are significant achievements in each of Goddard's lines of business.

Astrophysics

X-ray Advanced Concepts Testbed

Scientist Keith Gendreau leveraged past IRAD and other R&D funding to successfully propose the development of the X-ray Advanced Concepts Testbed. In FY 2009, he received a four-year, $2.95 million APRA award to ready the technology for a December 2011 sounding rocket flight, with a second to follow in mid 2012. The primary purpose of the mission is advancing the technology readiness level of several mission-enabling technologies, including modulated X-ray sources, X-ray polarimeters, and X-ray concentrators. It also will provide the first energy and phase-resolved X-ray polarization measurements of pulsars.



Principal Investigator Harvey Moseley is one of the scientists leading the effort to build CMBPol, a proposed instrument that would test the theories of cosmic inflation.

CMBPol and Cosmic Inflation

One of the most exciting challenges in astrophysics is testing the theories of cosmic inflation, the idea that the infant universe expanded from subatomic scales to the astronomical in a fraction of a second after its birth. To find proof, a team of Goddard scientists is developing an instrument — CMBPol — to detect a particular type of polarization signal in the cosmic background radiation that bathes the sky in all directions. In FY 2009, scientist Ed Wollack won $1.6 million in APRA funding to further advance the technology begun under IRAD and other Goddard R&D programs.

> "The proposed program was selected for funding, at least in part due to the work done under this IRAD program."
>
> – Harvey Moseley, CMBPol Instrument Scientist

MicroX

Principal Investigator Scott Porter also won $800,000 under a three-year APRA award to develop the MicroX sounding rocket mission that will study supernova remnants and galaxy clusters with Goddard's transition-edge X-ray microcalorimeter detectors. Microcalorimeter technology, which Goddard began developing in 1983 with R&D funding, has played a role in a number of missions and is weighing heavily in NASA's proposed International X-ray Observatory (see page 16).

Earth Science

Polarimeter for Next-Generation Mission

Principal Investigator Lorraine Remer received an additional $598,000 from multiple sources to enhance a multi-angle imaging polarimeter sensitive to the ultraviolet, visible, and near-infrared wavelength bands, thus maintaining Goddard's leading role in aerosol and cloud remote sensing. With her FY 2009 funding, Remer's team designed both the visible and near-infrared optics and is planning to fly a polarimeter on an ER-2 aircraft in the summer of 2010 — an event that should position the Center well for proposed Earth Science missions.

ASCENDS Laser Sounder

Goddard's positioning to lead the Active Sensing of Carbon Dioxide Emissions over Nights, Days, and Seasons (ASCENDS) mission improved in FY 2009 — thanks in part to IRAD funding. In testing, the ASCENDS team, led by Principal Investigator Jim Abshire, demonstrated carbon-dioxide and oxygen measurements in the lab and showed carbon-dioxide absorption levels over many days — an accomplishment that resulted in the team receiving a three-year, $2.4 million IIP award. The team also received an additional $500,000 in NASA funding to carry out airborne flight demonstrations in FY 2010.

> "This IRAD leveraged the capabilities our team has developed over the past eight years with support from the ESTO ACT and IIP programs."
>
> – James Abshire,
> ASCENDS Laser Sounder Principal Investigator

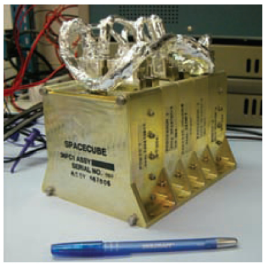
LIST Topographic Imaging Lidar

The Lidar Surface Topography (LIST) mission — recommended by the National Research Council — calls for a topographic imaging lidar to study terrestrial landscapes. Technologist Barry Coyle and his team won $250,000 in ESTO technology-development funding to advance the development of an all-fiber imaging lidar system needed to gather these measurements. The team has begun testing a full-power breadboard.

Space-Based Laser Instruments

Goddard remains a world leader in the development and deployment of space-based laser instruments. Principal Investigator Anthony Yu, who is leading an effort to develop more reliable, higher efficiency 885 nm diode-pumped ceramic neodymium-based laser systems for space applications, received $250,000 in ESTO funds in large part due to IRAD investments. The technology holds great promise for several next-generation Earth science missions.

Another SpaceCube Win


Principal Investigator Thomas Flatley is now developing the breadboard and flight prototype of a next-generation SpaceCube computer, which he calls SpaceCube 2.0.

Technologist Thomas Flatley, who received an FY 2009 IRAD Innovator of the Year Honorable Mention for his work advancing SpaceCube (see page 21) — won a $1.1 million AIST award to develop the breadboard and flight prototype of a next-generation SpaceCube computer, which he calls SpaceCube 2.0. The new system would be able to collect and process 10 times more data because it leverages both his "radiation-hardened-by-software" techniques and a new radiation-hardened field programmable array developed by Xilinx.

Principal Investigator Gerry Heymsfield is expected to fly his High-Altitude Imaging Wind and Rain Profiler on the Global Hawk unmanned aircraft in 2010.

Global Hawk Mission Planned

IRAD-funded scientist Gerry Heymsfield, meanwhile, received a $200,000 ROSES award to deploy the High-Altitude Imaging Wind and Rain Profiler on a Global Hawk mission in the summer of 2010. The instrument, which he conceived and built using a myriad of funding sources, including IRAD and IIP, will measure wind speeds and precipitation in a variety of weather systems. Heymsfield says he has proposed the instrument for other flight opportunities as well.

Photodiodes for Earth Science

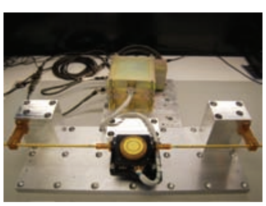
Technologist Michael Krainak leveraged previous IRAD-funded research to win a $1 million, three-year ESTO award to develop an ultra-sensitive, near-infrared optical receiver using silicon avalanche photodiode detectors. Krainak is using $150,000 of that award to test custom detectors built by his collaborator, Spectrolab, and is providing feedback for the next iteration of the design. The research could benefit next-generation Earth science missions.

CATS Lidar

Scientist Matt McGill, who used his FY 2009 IRAD funding to construct and demonstrate a receiver subsystem for the Cloud-Aerosol Transport System (CATS) lidar, also succeeded in winning an $835,000, two-year ESTO award to develop a detector subsystem for the instrument. According to McGill, NASA has expressed considerable interest in developing and fielding the CATS instrument.

Heliophysics

More Flight Opportunities for MINI-ME and PISA

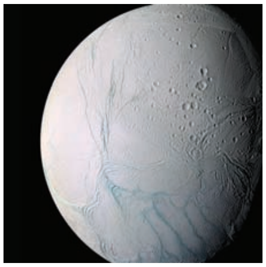


PISA, an IRAD-developed instrument, will be flying on a sounding rocket mission from Poker Flats, Alaska, in 2012.

Scientist Doug Rowland, who is flying his IRAD-funded PISA on a NASA-developed micro-satellite in 2010 (see page 5), has other plans for his instrument. With $1.6 million in NASA funding, Rowland is preparing for another sounding rocket mission — called VISIONS — from Poker Flats, Alaska, in 2012. In that mission, he and his co-collaborators will use PISA and another IRAD-developed instrument, MINI-ME, developed by scientist Michael Collier, to measure different processes in Earth's upper atmosphere and the effects of solar activity. Also in FY 2009, his colleague, Rob Pfaff, won $1.39 million to fly PISA on two sounding rocket missions planned for June 2011 from the Wallops Flight Facility. PISA will provide critical electron density information to measure the electrical conductivity of the lower ionosphere.

A Critical Assist

Another IRAD-developed technology could play a role in these heliophysics missions. With her R&D funding, technologist La Vida Cooper designed, simulated, and fabricated an analog-to-digital converter to enable solar and heliospheric imaging instruments. Rowland is now evaluating the technology for possible inclusion in PISA.

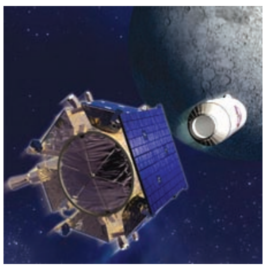


A Goddard team is developing a smaller version of an instrument that made remarkable discoveries on Enceladus, one of Saturn's tiny moons.

Planetary and Lunar Science

Infrared Spectrometer

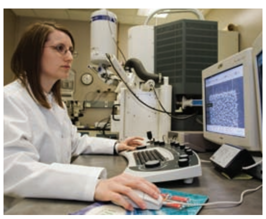
The Goddard-developed Composite Infrared Spectrometer produced important scientific results about the Saturnian system. As a result, the scientific community would like NASA to develop a follow-on, more capable instrument that is smaller, lighter, and consumes less power than the original for a future outer-planet flagship mission. In FY 2009, IRAD-funded Principal Investigator John Brasunas received a four-year, nearly $1 million NASA PIDDP award to continue construction of a prototype instrument.



The Goddard DREAM team says its research is more relevant than ever since the Lunar Crater Observing and Sensing Satellite mission discovered water on the Moon.

The DREAM Team

Thanks to IRAD funding, scientist William Farrell and his "DREAM team" won a $5 million, four-year research effort funded by NASA's Lunar Science Institute to develop advanced computer models to explore the interactions of solar radiation and solar wind on the Moon. The Dynamic Response of the Environment at the Moon (DREAM) team says the discovery of water on the Moon makes its research more relevant than ever.



Principal Investigator Stephanie Getty is applying IRAD-funded detector technology to develop a detector to locate breast cancer.

Detecting Life on Mars and Cancer Inside the Human Body

Technologist Stephanie Getty is using micro- and nano-fabricated methods to make components for a chemical field effect transistor, a low-power, highly sensitive detector for in-situ analysis of liquids. She has now found another application for her technology. Under a two-year, $120,000 grant from the National Institutes of Health, she is applying her technology to develop a nano-scale detector that would locate specific biomakers linked to breast cancer. The hope is that the NanoBioSensor Initiative will result in an instrument that physicians can use in a clinical setting.

Analyzing Mineral and Elements Without Sample Preparation

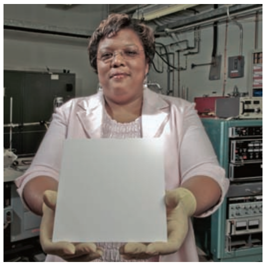
Efforts to create a technology that could more easily analyze minerals and elements on another planetary body took a step forward in FY 2009. Scientist Keith Gendreau used his IRAD funds to develop a laboratory prototype of his X-ray Diffraction and X-ray Fluorescence device. Envisioned as a portable device that could be carried on a rover or by an astronaut, the technology also received $250,000 in FY 2009 from the NASA PIDDP. The technology holds great promise for a variety of lunar and planetary science applications.

The Goddard team developing the Pulsed Neutron Generator Gamma-Ray and Neutron Detector poses in front of a granite formation it is using to test the instrument concept.

A New Neutron-Gamma Ray Measurement Approach

Principal Investigator Ann Parsons, with support from IRAD and $150,000 in PIDDP funding, developed an unusual test site — multiple granite slabs stacked in the middle of a field — to test the Pulsed Neutron Generator Gamma-Ray and Neutron Detector. The instrument could one day land on the Moon, Mars, Venus, or even the rocky moons of the outer planets to survey the elements found as much as a foot beneath their surfaces — without ever digging or displacing one gram of material. In FY 2009, the team completed the test site and developed a computer simulation tool, with the goal of testing her concept and ultimately proposing the instrument for a future mission.

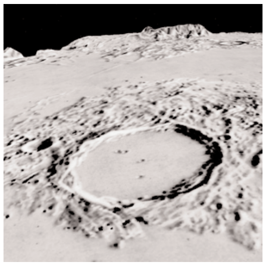
Exploration Technologies



Wanda Peters holds a Lotus coating-covered sample that she and her team are currently testing for spaceflight applications.

Borrowing from Nature: Lotus Coatings

Mother Nature — and more specifically the aquatic lotus plant — inspired a Goddard team headed by engineer Wanda Peters to develop a special coating to prevent dirt and even bacteria from sticking to and contaminating the surfaces of spaceflight gear. In addition to receiving IRAD funding to advance the technology, Peters has received funding from NASA Headquarters. In FY 2009, Peters reported that NASA's ETDP increased funding levels to $176,000 in FY 2010 and $175,000 in FY 2011. The Constellation Program also is investigating additional funding for Peter's work.



This image, taken by Clementine, is a sample of the data that would be available on ILIADS, a Goddard-developed geospatial information system.

Lunar Mapping and Modeling

Technologist Steve Talabac received two follow-on awards related to ILIADS, an IRAD-funded software application that provides easy access to geographic and environmental lunar data. NASA's Lunar Mapping and Modeling Project awarded $1.25 million to Talabac's team to provide an enhanced version of the ILIADS software, which would interface with a Web portal and lunar-data product server developed by the Jet Propulsion Laboratory (JPL). He also received $500,000 from the Exploration Systems Mission Directorate to help develop the Lunar Surface Operations Simulator, which JPL is developing to model and simulate the performance of lunar rovers.

New Capabilities and Collaborations

Principal Investigator Ken Segal poses with the model he used to develop a carbon-fiber reinforced plastic thermal shield — technology that earned him a leadership role in the Advanced Composites Technology effort.

Advanced Composites

A couple years ago, technologist Ken Segal applied for IRAD funds to enhance Goddard's ability to infuse lightweight and multi-functional composite materials into spacecraft structures. The investment has paid off. In FY 2009, Segal and his team were given the leadership role in the ETDP Advanced Composites Technology effort, managed by the Langley Research Center. Segal received nearly $4.3 million for FY 2010-2014. (Investment Area: Exploration Technologies)

> "Thanks for your support over the last two years, as it was absolutely pivotal in helping Goddard secure the Composites Joints leadership role."
>
> – Ken Segal,
> Advanced Composites Technology Lead

Extreme Environment Low-Temperature ASICs

Principal Investigator La Vida Cooper is using IRAD funds to develop low-temperature application-specific integrated circuits.

Instruments operating in lunar and planetary environments would benefit from application-specific integrated circuits (ASICs) capable of withstanding extremely low temperatures. Technologist La Vida Cooper, using her FY 2009 IRAD funds, verified new low-temperature transistor models needed to design and simulate ASICs. As a result of these efforts, Cooper entered into a Space Act Agreement with Sensing Machines, a small-business partner, which assisted in testing. (Investment Area: Strategic Crosscutting Capabilities)

The CAVE

Technologist Dave Folta stands inside the CAVE, Goddard's newest visualization lab.

In FY 2009, Goddard technologists opened a new visualization lab developed in part with IRAD funds. Appropriately named the CAVE, the facility is a dark, relatively small space where users wear special 3D eyewear and carry a wand to command and control 3D visualizations of spacecraft designs and complex orbits and trajectories. Principal Investigator Steve Queen used IRAD funds to develop algorithms and other technology to develop the facility's workstation simulator. The CAVE is now available to engineers and scientists who need to "see" or interact with complex systems before they commit to their designs. (Investment Area: Strategic Crosscutting Capabilities)

Imaging Detector Algorithm Prototyping Testbed

With IRAD funding, technologist Robyn King produced a Center-wide testbed facility for colleagues who use CMOS imaging detectors to prototype their readout electronics and algorithms. Located in Building 11, the testbed allows different CMOS imaging detectors to share a common reusable FPGA hardware framework. (Investment Area: Strategic Crosscutting Capabilities)

Dynamics Analysis and Visualization Tool

Principal Investigator Dean Chai developed the Dynamics Analysis and Visualization Tool for the Mission Design Laboratory (MDL). The technology provides customers with rapid prototype design capabilities and allows them to perform simple follow-up trade studies as well as visualizations during their MDL studies. As a result of his work, MDL is interested in using its resources to fund the tool's future development. (Investment Area: Space Communications and Navigation)

Non-Redundant Aperture Solver and Visualizer Tool

Future space-based interferometry missions will require high-angular resolution imagery across the ultraviolet, visible, and infrared wavelength bands. However, achieving the required resolution is neither practical nor cost-effective with a single aperture. The challenge is combining multiple apertures with interferometry techniques. In FY 2009, Principal Investigator Nargess Memarsadeghi developed a Non-Redundant Aperture (NRA) Solver and Visualizer Tool for astrophysicists. In the future, Memarsadeghi plans to promote the NRA solver and visualizer within the astrophysics community. (Investment Area: Astrophysics)

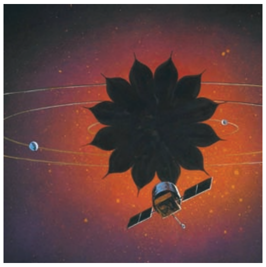
Orbit Determination Toolbox

The Orbit Determination Toolbox is a Matlab-based analysis toolset that provides a more flexible way to carry out early mission studies. Although it is intended for future mission concept studies, Goddard technologists already have used it to support a number of space science missions and exploration studies. With IRAD funding, Principal Investigator Kevin Berry expanded the toolbox to include a limited set of measurement models used in batch and sequential orbit-determination analyses. (Investment Area: Space Communications and Navigation)

Exoplanet Discovery

In FY 2009, the IRAD program funded a handful of concept studies for finding and characterizing planets around nearby stars — considered one of the most exciting research areas in astrophysics today. (Investment Area: Astrophysics)

- In one IRAD-funded effort, scientist William Danchi focused on an enhanced version of the **Fourier-Kelvin Stellar Interferometer** that could detect and characterize super Earths down to Earth-sized planets and found that the design offered no showstoppers. He has since submitted proposals for follow-on NASA funding.



This artist's concept shows the giant sun-shade, which would fly in formation with a next-gen-eration telescope to block starlight and help reveal the presence of planets.

- In another study, Principal Investigator Mark Clampin and his team evaluated a visible nulling coronagraph (VNC) for the Extrasolar Planetary Imaging Coronagraph, a mature Goddard-led mission to detect and characterize Jovian-like planets and dust or debris disks around nearby stars. The VNC would be coupled to a telescope to interferometrically suppress starlight and increase the contrast of the circumstellar region surrounding the star. Astronomers then could image the planet. The effort was productive. With IRAD and other funding, the team iterated and tested multiple VNC designs, ultimately submitting proposals to NASA Headquarters for follow-on funding.

- Also challenging is looking for planets that lay within the habitable zones of their parent stars. While several internal coronagraphic approaches are available (see above) to make the planet visible, an alternative exists. With IRAD funding, a team led by Richard Lyon studied an external occulter or starshade that would fly between the target star and the telescope. As part of its IRAD funding, the team designed a testbed that would help advance the technology, finding that a testbed is feasible, with a minimal investment.

JWST Follow-On

The Hubble Space Telescope is expected to operate until 2015, when the James Webb Space Telescope (JWST) launches and assumes operations until the 2020-2025 timeframe. However, no large space telescope currently is planned for the post-JWST period. Given the 20-year development time for a flagship mission, NASA planners must begin now to investigate a potential follow-on to JWST. Scientist William Oegerle used IRAD funding to develop a concept for a large optical space telescope, called ATLAST-9.2m. Specific technologies identified in the study will be pursued with funding from a variety of sources. (Investment Area: Astrophysics)

> "Given the 20-year development time for a flagship mission, one must start now to minimize the expected gap in capabilities after JWST ceases to operate."
>
> – William Oegerle, ATLAST-9m Principal Investigator

Patent Applications

Nanostructure Mirrors

The diffraction of light limits the resolving power of all imaging systems, making it difficult to isolate the image of faint objects near bright objects. With IRAD funding, Principal Investigator John Hagopian has investigated methods to develop a mirror geometry using nanostructures to suppress classical "Airy" rings that limit many scientific observations. In FY 2009, Hagopian reported that some of his work is advancing through the patent process and that other Goddard technologists are interested in applying his technology to their own R&D efforts. (Investment Area: Strategic Crosscutting Capabilities)

New Laser Altimetry Measurement Approach

In laboratory and outdoor experiments, Principal Investigators Jim Abshire and Xiaoli Sun demonstrated that a novel measurement approach for high-priority laser altimetry and trace gas lidar applications was flexible and would benefit future Earth and planetary laser missions. As a result of their work, they filed a patent application with the U.S. Patent Office. (Investment Area: Strategic Crosscutting Capabilities)

Four

Notable Achievements: Technologies to Watch

R&D investment programs are high-risk endeavors. In some cases, the research does not yield the expected outcome or result. In other cases, the principal investigator achieves precisely what he or she set out to accomplish. Here we spotlight a few IRAD-funded efforts that are making significant headway and could one day result in Goddard winning new work and help NASA to carry out its science and exploration missions.

> "With APRA funds alone, we would continue detector development, but we would not be able to execute the major milestones of the XMS technology roadmap on a timescale useful for the AO competition."
>
> – Caroline Kilbourne, Principal Investigator, X-ray Microcalorimeter Spectrometer

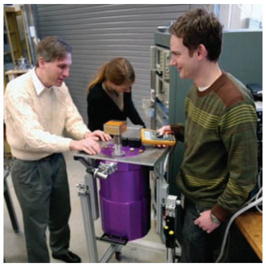
Astrophysics

Technology Advances for the International X-ray Observatory

Goddard scientists are pushing the technological envelope to develop a variety of technologies needed for NASA's next-generation X-ray telescope, the International X-ray Observatory (IXO). IRAD has funded advances in grazing-incidence, segmented mirrors as well as mirror-assembly techniques that would result in an unprecedented photon-collection area of up to 30 times the collection area of the Chandra X-ray Observatory. It also has funded new detector technology — transition edge sensors — critical for a next-generation X-ray Microcalorimeter Spectrometer. Principal Investigators William Zhang, Peter Blake, and Caroline Kilbourne say their work is positioning the Center to win a significant piece of IXO should NASA begin the mission.

Microcalorimeter Arrays

In another development in microcalorimeter technology, Principal Investigator Wen-Ting Hsieh developed a potentially revolutionary technique for producing a new type of spectrometer — the magnetic penetration depth thermometer, which can achieve sub-eV sensitivities in geometries suitable for large arrays. In FY 2009, Hsieh and her team fabricated a microcalorimeter array and realized that they had inadvertently produced a microcalorimeter that detected X-rays through a different mechanism than designed. The team detected X-rays through the superconducting properties of a thin niobium adhesion layer. The team reports that the technology can be revolutionary in achieving very large, megapixel arrays. Work is continuing.



Principal Investigator Al Kogut (left) works with students on his PIPER payload.

Primordial Inflation Polarization Explorer

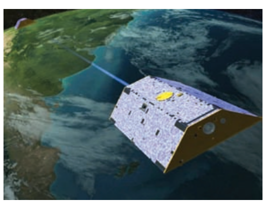
Principal Investigator Al Kogut successfully built a prototype detector for the Primordial Inflation Polarization Explorer, a balloon payload that will search for the gravity wave signal of cosmic inflation, a theory that postulates that the universe expanded far faster than the speed of light after its creation. The IRAD-funded work, which is raising the technology readiness levels of key subsystems, could lay the technological foundation for an even more sophisticated mission in the future.

Earth Science

Ocean Radiometer for Carbon Assessment

Building on work that Goddard scientists pioneered in the development of ocean color sensors, Principal Investigator Chuck McClain is developing the Ocean Radiometer for Carbon Assessment (ORCA) instrument under IRAD funding. In FY 2009, he reported that the ORCA team is proposing a sensor for an aircraft demonstration flight.

Space-Qualified Laser



Goddard technologists are leveraging their expertise in laser-ranging technology to develop an instrument that could fly on the follow-on to the enormously successful Gravity Recovery and Climate Experiment.

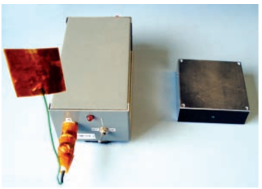
The science community has recommended a follow-on mission to NASA's enormously successful Gravity Recovery and Climate Experiment. The center that develops the instrument component for the proposed mission likely will be the one that leads in laser-ranging technology. Principal Investigator Matthew Rodell and Jordan Camp are leveraging Goddard's current leadership to put Goddard in a strong position to build lasers for a successor mission.

Quantum Well Infrared Photodetectors

Quantum Well Infrared Photodetectors (QWIPs) are a versatile class of infrared detectors based on the band-gap engineering of gallium arsenide (GaAs) semiconducting materials. Relatively easy to fabricate, the technology could be applied to the Thermal Infrared Sensor (TIRS), which will fly on the Landsat Data Continuity Mission. Using IRAD and other funds, Principal Investigator Murzy Jhabvala developed large-format infrared GaAs QWIP arrays. The team plans to apply for future NASA Headquarters funding to develop the QWIP technology for other Earth science applications and develop still larger format arrays of up to 2,000 x 2,000 pixels.

Exploration Technologies

MoPED: Astronaut Charging



Principal Investigator Telana Jackson is advancing electronics, which are shown here, for the Moon Portable Electrostatic Detector. The proposed miniaturized electrometer could detect surface charging on spacesuits and equipment.

Principal Investigator Telana Jackson made significant progress advancing the Moon Portable Electrostatic Detector (MoPED), a small, miniaturized electrometer that would detect surface charging on spacesuits and equipment. In FY 2009, Jackson procured hybrid prototypes of the technology from MicroPac Industries. While exploration opportunities remain uncertain, the technology could be applied to scientific missions to Mars and even the study of terrestrial thunderstorms.

Heliophysics

Plasma Wave Experiment

Principal Investigator Robert Pfaff broke new ground in the development of the Plasma Wave Experiment, which could fly on a future heliophysics mission. The team's accomplishments included the development of an antenna design and a candidate probe system that could meet the stringent thermal, mass, and other engineering requirements of a future mission. The team believes that the outlook is promising.

> "Among its many accomplishments, this IRAD was used to develop an antenna design with industry and design a candidate system that meets stringent thermal, mass, and other engineering requirements."
>
> – Robert Pfaff, Principal Investigator, Plasma Wave Experiment

ECHOES Prototype

Principal Investigator Mark Adrian and his team prototyped a Virtex-5, FPGA-driven transmitter/receiver board and switch for the Electron Concentration vs. Height from an Orbiting Electromagnetic Sounder (ECHOES) experiment. The sounder is a low-power, low-mass radio-sounding experiment that has multiple applications for future ionospheric missions. The team now expects to field test the technology over the coming weeks and propose further development of a flight instrument through various NASA funding programs.

Planetary and Lunar Science

Prototype Electron Gun/Si-Drift Detector

Principal Investigator Lucy Lim continued her work unifying two advanced technologies: a Goddard-built carbon nanotube electron gun and a large-area silicon-drift detector to ultimately develop a miniaturized, portable X-ray spectrometer for planetary science and manned exploration missions. The instrument could provide rapid, highly sensitive analyses of lunar and planetary rocks, soils, and ice. In FY 2009, Lim and her team advanced an active X-ray spectroscopy instrument and applied for follow-on NASA funding.

Sealable Microleak

The sealable microleak, which will benefit planetary science, is a device that precisely controls inlet flow rates for mass spectrometers currently under development in the Atmospheric Experiments Laboratory. In FY 2009, Principal Investigator Mary Li completed the design of single-channel devices in a three-wafer format and now plans to design multi-channel devices in FY 2010. She currently is collaborating with Goddard technologists Paul Mahaffy and Dan Harpold.

Communications and Navigation

Formation-Flying Modeling

Principal Investigator Neerav Shah used FY 2009 IRAD funds to develop a formation-flying modeling and analysis tool. The technology will help study the precise relative navigation and control technologies needed for the Milli-Arc-Second Structure Imager Mission and New Worlds Observer. As a result of her work, Shah has partnered with Ball Aerospace, the University of Colorado, Princeton University, and Sigma Space Corporation on a proposal effort — a development that could not have happened without IRAD support.

Strategic Crosscutting Capabilities

3D Imager for Mapping, Docking and Robotic Vision

Principal Investigator Tony Yu used FY 2009 IRAD funds to advance the laser transmitter system and other optics to ultimately build a practical and compact short-to-long flash Lidar 3D imaging system, which would capture illuminated scene information with a single shot at a maximum rate of 10,000 shots per second. The potentially revolutionary technology has multiple applications in space science, exploration, and communications and navigation.

Five

Recognizing Goddard's Top Performers

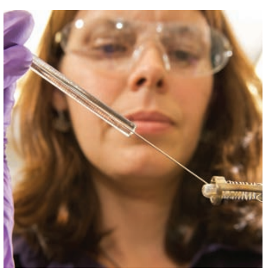
Eigenbrode and Flatley Win IRAD Innovation Awards

Deputy Director Laurie Leshin (right) presented the Office of the Chief Technologist's "Innovator of the Year" awards at the annual FY 2009 Poster Session. Tom Flatley and his team won an honorable mention for advancing SpaceCube and Jennifer Eigenbrode won the top prize for her work developing a sample-preparation experiment that will fly on the Goddard-built Sample Analysis at Mars instrument.

The Office of the Chief Technologist selected Goddard scientist Jennifer Eigenbrode to receive its 2009 "IRAD Innovator of the Year" award because of her work validating a sample-preparation method that enhances the ability of the Sample Analysis at Mars to analyze large carbon molecules if they are discovered on Mars.

Also recognized were Thomas Flatley and team, whose contributions earned them an honorable mention for advancing a state-of-the-art hybrid computer system — SpaceCube — that provides 15 to 25 times the processing power of a typical flight processor. The accompanying articles detail the significance of their work.

Eigenbrode's Experiment Enhances Ability to Find Life on Mars



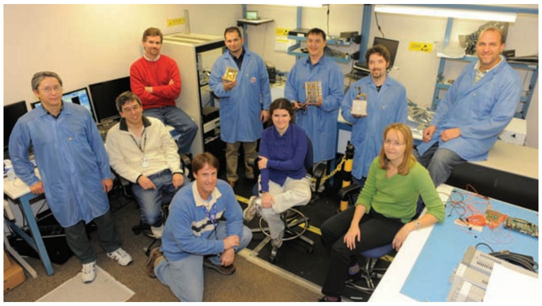
Scientist Jennifer Eigenbrode validated a new experiment that will fly on the Sample Analysis at Mars instrument — an accomplishment that earned her the FY 2009 IRAD Innovator of the Year award.

Goddard scientist Jennifer Eigenbrode, an expert at detecting organic compounds in rocks, spent the past couple years investigating methods that would give a robotic laboratory operating millions of miles from home the same flexibility and capability of an Earth-based organic geochemistry laboratory. In FY 2009, her efforts paid off.

Her experiment has been incorporated into the Goddard-developed Sample Analysis at Mars (SAM) instrument, one of 10 flying on the Mars Science Laboratory. The car-sized rover will launch next decade to analyze dozens of samples scooped from the soil and drilled from rocks to assess whether Mars now or ever sustained life.

Eigenbrode secured the flight opportunity after successfully proving in a series of IRAD-funded tests earlier this year that thermochemolysis — the combination of heat and a specific chemical — would significantly enhance SAM's ability to analyze large carbon molecules if they are discovered on Mars. Should the mission find large organic molecules — potential precursors or artifacts of life that are made up of smaller molecules such as carbohydrates, lipids, proteins and nucleic acids — Eigenbrode's experiment will reveal far more details about their evolution.

Her contribution to SAM will significantly enhance scientists' understanding of organic carbon sources and processing on Mars. (Investment Area: Planetary and Lunar Science)



The Office of the Chief Technologist recognized Tom Flatley and his SpaceCube team for their work advancing the next-generation flight computer system. Team members include (from left to right): Manuel Buenfil, Mike Lin, Tom Flatley, Ed Hicks (kneeling), Danny Espinosa, Robin Ripley (seated), Gary Crum, Alessandro Geist, Karin Blank, and Jeff Hosler. Not pictured is Dave Petrick.

SpaceCube Flies Twice

Just a few months after successfully demonstrating their next-generation computer system during the Hubble Servicing Mission, Tom Flatley and the SpaceCube team exhibited yet another potentially revolutionary application, further showcasing the viability of the Goddard-grown technology.

SpaceCube, a highly versatile hybrid computer that provides up to 25 times the processing power of a typical flight processor, demonstrated an innovative radiation-hardening technology that would make flight processors more immune to radiation upsets. The experiment was attached to NASA's Express Logistics Carrier, which astronauts delivered to the Space Station on STS-129 in November 2009.

> "The success of these two IRAD investigators truly exemplifies the impact and value that innovation can bring to the Agency. NASA and the broader scientific community will gain much from their contributions."
>
> – Peter M. Hughes, Chief Technologist

Earlier in the year, SpaceCube also played a pivotal role in the relative navigation experiment carried out during the Hubble Servicing Mission a few months earlier. As the Shuttle approached the telescope, SpaceCube ran in parallel to simulate the exacting docking maneuvers. It calculated the position and orientation of the observatory relative to the Space Shuttle.

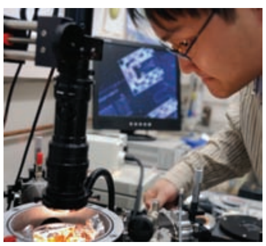
The future looks bright for SpaceCube. The team also is demonstrating SpaceCube on an upcoming sounding rocket flight in Fall 2010, and is developing the "next generation" SpaceCube for Earth Science flight opportunities beginning in Spring 2012. The team is also collaborating with a number of industry vendors interested in commercializing the system. (Investment Area: Strategic Crosscutting Capabilities)

Six

Early-Stage Innovations: What the Future May Hold

What's the next innovative technology, the game-changing approach that will enable never-before-imagined science or significant leaps in capability? In FY 2009, the IRAD program funded a handful of "early-stage innovations," longer-range technologies that could provide the revolutionary new capability needed for next-generation astrophysics, Earth science, heliophysics, planetary and lunar science, or exploration missions. These technologies could take years to ultimately mature; however, their potential is enormous for securing Goddard's expertise in areas that the Center has deemed important to its future.

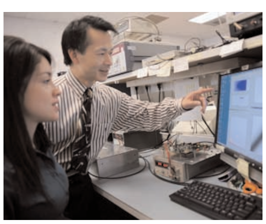
Scaling Up Detector Arrays



Kongpop U-Yen

Obtaining high-resolution data of faint or very distant objects will require technologists to build instruments equipped with large detector arrays containing literally thousands of tiny pixels. Getting to that next level of sophistication, however, is easier said than done. Technologists not only have to develop ways to more easily assemble these detector arrays, they also have to come up with better ways to "wire" them so that the data they collect are efficiently transmitted to read-out systems. Goddard technologist Kongpop U-Yen used IRAD funds to investigate ways to minimize the number of output wires by developing a technique where the pixels would share the same transmission line, freeing up space, and ultimately improving technologists' ability to scale up the pixel density needed for next-generation missions. (Investment Area: Astrophysics)

Compressing Radar Data



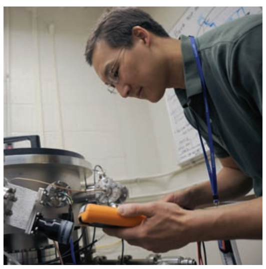
Wai Fong

Remote-sensing instruments generate copious amounts of information that must be compressed and stored until the user retrieves it. Not only are data-processing systems complex — requiring, for one, a complicated data-sampling step — errors can propagate when the user decompresses the data. Goddard technologist Wai Fong and his team are trying to develop new ways to record the data so that they are sampled and compressed in one simple process on the instrument itself. This would eliminate the need for complex onboard data-processing equipment, which would reduce spacecraft weight. Now focused on radar applications, Fong says the technology could be applied to other types of high-data-rate measurements. (Investment Area: Strategic Crosscutting Capabilities)

Emily Wilson

Measuring Martian Methane

In 2009, Goddard scientist Mike Mumma announced he had used ground-based telescope data to definitively detect methane plumes in the northern hemisphere of Mars. Its detection made headlines because it showed that Mars still could be alive — either biologically or geologically. Not surprisingly, discovering the source of these gases is a science priority and will require additional missions to the planet itself. Goddard scientist Emily Wilson believes a smaller gas correlation radiometer, particularly one that implements a hollow optical fiber to reduce the size of the instrument, offers an ideal solution for globally pinpointing the source of methane on Mars. IRAD funding is allowing her to develop this reduced-size instrument and make it viable for a Mars orbiter or lander mission. Wilson has submitted a proposal for the 2010 Planetary Instrument Definition and Development Program. (Investment Area: Planetary and Lunar Science)



Todd King

Developing a Miniaturized Mass Spectrometer

The next-generation mass spectrometer needed to discover the origin and history of Mars, Venus, the Moon, and other solar system bodies will have to be smaller and even more capable than current instruments. With IRAD funding, technologist Todd King and his team have demonstrated a small, low-weight, high-resolution time-of-flight mass spectrometer made of micro- and nano-fabricated components. The Volatile Analysis by Pyrolysis of Regolith project, headed by technologist Daniel Glavin, will fund future development efforts. (Investment Area: Planetary and Lunar Science)

Kevin Fisher

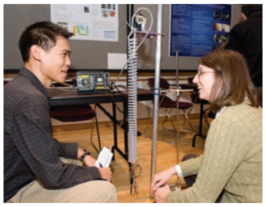
Tailoring Hyperspectral Datasets

Earth scientists can learn much from hyperspectral data — everything from identifying mineral deposits and land-use changes to detecting and mapping fires, chemical spills, and even floods. However, only a small portion of a hyperspectral image is useful for identifying any given material. Furthermore, material-classification programs that analyze images run slowly because these images contain so much data. Under his FY 2009 IRAD, Kevin Fisher developed an algorithm — called Progressive Band Selection — to quickly analyze hyperspectral images and select the most useful spectral bands for a given science application. Fisher applied for a provisional patent in 2009. (Investment Area: Earth Science)

Seven

Future: Unleashing the Entrepreneurial Spirit

The Office of the Chief Technologist used the FY 2009 IRAD Poster Session as a venue to offer technologists another spontaneous IRAD opportunity called "Connect & Innovate."



At the FY 2009 IRAD Poster Session, technologist Alvin Yew talks with colleague Stephanie Getty about the ice drill he developed with R&D funds. The pair, along with other colleagues, ended up winning a "Connect & Innovate" spontaneous IRAD to apply Yew's ice drill to new applications.

Indeed, we have become more strategic in the way we fund R&D, focusing in large part on identified opportunities and the technologies needed to win these missions or instrument-development efforts. However, that is only part of the story. In FY 2009, we dedicated a larger percentage of our R&D resources to longer- term technologies that map to our strategic lines of business. These investments were aimed at allowing technologists to unleash their creativity and innovation to conceive far-reaching technologies for future missions and instrument concepts.

This will continue. In fact, we are stepping up efforts to encourage collaboration and innovation in the hope that technologists will think big. At the FY 2009 Poster Session, for example, we offered attendees an opportunity to submit proposals under our new spontaneous IRAD initiative, called "Connect & Innovate." Principal investigators were encouraged to find a partner, identify a novel forward-reaching collaboration, and submit a compelling idea. Within a few days, we had selected two teams to receive funding: Paul Racette and Haris Riris will investigate a new analytical method to calibrate laser remote-sensing instruments. Also selected was a proposal offered by Alvin Yew, Jason Dworkin, Jennifer Eigenbrode, Stephanie Getty, Daniel Glavin, and Natasha Johnson. The team will investigate a tool that would extract ice and icy regolith and convert the sample to liquid form while on an airless, icy surface.

A few months earlier, we awarded a "Connect & Innovate" award to Brian Dennis and Keith Gendreau to demonstrate new capabilities for high angular resolution X-ray imaging that could be used for both heliophysics and astrophysics.

We also are planning other programs to encourage innovation, including "Open Space 2 Innovate," a daylong, facilitated forum for Goddard employees to come together and talk about innovative ideas across grade level, skill, function, discipline, tenure, expertise, and the Goddard lines of business.

Programs like "Connect & Innovate" and "Open Space 2 Innovate" are designed to invigorate creativity and innovation and create opportunities that result in meaningful work for all employees. More important, a culture of innovation can give the Agency the solutions it needs to make the revolutionary discoveries that the public has come to expect from NASA.